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WATER RESOURCES ACTIVITIES IN THE UNITED STATES. APPLICATION AND EFFECTS OF NUCLEAR ENERGY

Select Committee on National Water Resources, U. S. Senate

December 1959

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WATER RESOURCES ACTIVITIES
IN THE
UNITED STATES

APPLICATION AND EFFECTS OF NUCLEAR ENERGY

SELECT COMMITTEE ON NATIONAL WATER RESOURCES
UNITED STATES SENATE

PURSUANT TO

S. Res. 48

EIGHTY-SIXTH CONGRESS
FIRST SESSION

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STATEMENT BY THE CHAIRMAN

DECEMBER 18, 1959.

To the Members of the Senate Select Committee on National Water Resources:

Senate Resolution 48 directs our committee to consider new technical methods that may increase the usefulness of available water supplies and refers to the application of nuclear energy, among other possibilities. In the field of peaceful applications of atomic energy there are many subjects with which the committee will wish to concern itself. These include, among others, the production of electric energy from nuclear sources, both as a use of water or in relation to changes in the electric power industry which might be brought about by increased use of nuclear energy; nuclear products likely to affect water withdrawal or water quality; waste disposal problems from nuclear industries as they may affect water resources; use of nuclear energy for desalinization of sea water; future water requirements for the nuclear industry; and prospective uses of nuclear energy techniques in connection with basic data collection, improved water use, and other aspects of water resources development.

Under the Atomic Energy Act of 1954, the Atomic Energy Commission has broad responsibilities in all these fields. Therefore, I asked the Commission to prepare a report for the committee giving background on what is to be expected, and suggestions as to what should be done in the field of nuclear energy in relation to water supply problems.

The report prepared in response to my request will be of interest to you, to the other Members of the Senate, and to others concerned with finding solutions to the Nation's water problems. Therefore, I am having it printed as one of our committee prints dealing with aspects of water resource activities which are being considered by the committee.

ROB'T S. KERR,
Chairman, Select Committee
on National Water Resources.

COMMUNICATIONS

U.S. SENATE,
SELECT COMMITTEE ON NATIONAL WATER RESOURCES,
July 13, 1959.

MR. JOHN A. MCCONE,
Chairman, Atomic Energy Commission,
Washington, D.C.

MY DEAR MR. CHAIRMAN: Under the provisions of Senate Resolution 48 adopted April 20, 1959, a copy of which is enclosed, a committee composed of Senators from each of the Committees on Agriculture and Forestry, Interior and Insular Affairs, Interstate and Foreign Commerce, and Public Works has been established and steps are being taken to assemble and analyze information concerning the many complex phases of the Nation's water problems.

Under the provisions of the resolution the committee is directed to make full use of studies and plans prepared by executive agencies and the agencies are requested to give such assistance as may be required. In this connection it is expected that the Atomic Energy Commission will be able to furnish the committee information with respect to the application of nuclear energy in relation to water use and supply. As a first step in this field it is requested that a report be prepared for the committee to provide background on what is to be expected and suggestions as to what should be done in the field of nuclear energy in relation to water supply problems.

We would suggest that the report be prepared under the title of "Effects of Nuclear Energy on Water Use and Supply" and that it contain information on the following subjects:

1. The Commission's assumptions as to the levels of electric energy production from nuclear sources from 1970–1980, and of other uses of nuclear products likely to effect water withdrawal or water quality.

2. An analysis of expected waste disposal problems in 1980 from nuclear industries with suggestions for any special measures in water resource development which may be necessary to meet these problems.

3. Effects of the assumed 1980 level of atomic electric energy production upon the need for and design of hydroelectric plants, giving regional variations in these effects, if any.

4. Water required for nuclear industry for 1980 giving amount and quality and regional distribution so far as practicable.

5. Prospective uses of nuclear energy techniques in basic data collection, construction, improved water uses, and other aspects of water resource development and estimates of likely effects of these techniques on costs of development.

6. The Commission's recommendations for Federal participation in further research on the above subjects and recommendations as to the character of legislation to encourage application of nuclear energy and any other specific measures in water development planning that might help in meeting nuclear industry requirements.

We would like this information to be made available, if possible, in a summary report of not more than about 10,000 words, with whatever tables, charts, appendixes, and graphic illustrations as may be considered necessary. It would be most helpful if this information could be furnished the committee by October 15, 1959.

The committee would also like a separate study covering the most recent developments in the field of application of nuclear energy for desalinization of brackish and ocean waters. It is understood that the Commission is working on the possibilities of con bining nuclear reactors for the production of electric energy with desalinization plants and we would like to be given your best estimates of the potentialities of such plants and your recommendations as to what action might be taken to encourage progress in this field.

The committee has appointed a small staff, of which Mr. Theodore M. Schad is director. The staff will be glad to discuss any problems which might arise in the preparation of these reports with representatives of the Atomic Energy Commission.

Sincerely yours,

ROB'T S. KERR, *Chairman.*

U.S. ATOMIC ENERGY COMMISSION,
Washington, D.C., November 3, 1959.

Hon. ROBERT S. KERR,
Chairman, Select Committee on National Water Resources, U.S. Senate.

DEAR SENATOR KERR: A report entitled "Effects of Nuclear Energy on Water Use and Supply in the United States" will be completed and submitted to you within the next 10 days in accordance with the request contained in your letter of July 13, 1959

We wish to acknowledge with thanks the beneficial discussion between members of the AEC staff and Mr. Theodore M. Schad, executive director of your committee staff, and Mr. E. A. Ackermann, a consultant to your staff, prior to the preparation of this report.

In general the information that will be contained in the report indicates that at least in the next decade and very likely up to 1980, the requirements and applications of a nuclear energy technology will not have a major effect or impact on water resources utilization or development.

With respect to water use for cooling purposes, it appears that on an equivalent installed kilowatt basis, nuclear powerplants will require essentially the same amount of water as fossil-fueled powerplants. Therefore, although estimates of the amount of nuclear capacity that will be installed in the coming years vary widely, any predictions of cooling water use based solely upon expected growth in power generation capacity, will not be significantly affected, whether or not nuclear power becomes a significant element of our total generating capacity.

With respect to the waste disposal problems associated with the nuclear energy industry, it is difficult to foresee any continuing operating situation in which specific water requirements would be generated for the purpose of diluting low-level liquid wastes which would be dispersed to the environment. Because of the nature of radioactive materials as a potential environmental contaminant, it is essential that dispersal operations be controlled so as to preclude such requirements. The technology for such control is either presently available or is relatively straightforward. Accordingly, it is envisioned that the industry will operate in a manner that assures no significant effect on water quality.

Since the nuclear energy industry is in its early stages of development, the speculative nature of future quantitative estimates is emphasized and the difficulty of refining such estimates to delineate regional distributions or variations is noted.

Nuclear energy techniques that may also be useful in water resources development are of considerable interest to the AEC and other specialized Federal agencies, particularly the U.S. Geological Survey, directly concerned with water resources. Although the development and application of such techniques should be encouraged to the fullest possible extent, it is apparent that they are tools for use by the hydrologist, geologist, and other water resource specialists and are not new methods nor avenues for water resources development.

With respect to the application of nuclear energy to the desalinization of ocean and brackish waters, it is concluded that the extent of such application is first of all dependent on our ability to produce competitive electrical energy and/or process heat. Although it is estimated that competitive low-

temperature steam from nuclear plants may be possible in the next decade, it even then does not necessarily follow that competitively priced usable water will thereby be produced from saline sources.

We would be glad to discuss the details of this report with you or your committee or staff should you so desire.

Sincerely yours,

A. R. LUEDECKE, *General Manager.*

U.S. ATOMIC ENERGY COMMISSION,
Washington, D.C., December 1, 1959.

Hon. ROBERT S. KERR,
Chairman, Select Committee on National Water Resources,
U.S. Senate.

DEAR SENATOR KERR: The enclosed report, "Effects of Nuclear Energy on Water Use and Supply," is submitted to you in accordance with my letter of November 3, 1959.

We do not, at this time, have any major recommendations for Federal agency activities in this area or for suggested legislation for application of nuclear energy to water resources development. We believe that existing pertinent legislation is adequate for AEC purposes. Our belief that existing interagency programs in this field should be continued and encouraged is also noted.

We would be glad to discuss the details of this report with you or your committee or staff should you so desire.

Sincerely yours,

R. E. HOLLINGSWORTH,
Deputy General Manager.

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EFFECTS OF NUCLEAR ENERGY ON WATER USE AND SUPPLY

Introduction

This report was prepared as a result of a request from the Select Committee on Water Resources of the U.S. Senate. In his request to the AEC, the chairman of the committee noted the desire for information to provide background on what might be expected and suggestions as to what should be done in the field of nuclear energy in relation to water supply problems. Certain specific areas in which information was desired were delineated and included—

1. Estimates of levels of electric energy production from nuclear sources to 1980 and of other uses of nuclear products and their effect on water use and quality.
2. Expected nuclear energy wastes to 1980 and their impact on water resource problems.
3. Effects of nuclear energy production on hydroelectric plant development.
4. Overall nuclear industry water requirements to 1980.
5. Application of nuclear techniques in water resource development.
6. An appraisal of the application of nuclear energy for desalinization of brackish or ocean waters.
7. Recommendations for future Federal activities in these areas and the character of legislation to encourage application of nuclear energy to water resources development.

I. Estimates of Nuclear Power Growth

Various estimates have been made of the growth of nuclear power in the United States. Some of these predictions have been performed by Lane (Nucleonics, October 1954); Knowlton (Electrical World, vol. 141, No. 16, 1954); Davis (Engineering News Record, Apr. 22, 1955); Atomic Industrial Forum (Growth Survey, 1955); Report of the Panel on the Impact of the Peaceful Uses of Atomic Energy, January 1956; Davis and Roddis (speech for the Fifth Atomic Energy in Industry Conference, Mar. 14, 1957); and Cohen (Nucleonics, January 1958). These estimates of nuclear electrical generating capacity vary from 10,000 to 23,000 megawatts in 1970 and from 42,000 to 227,000 megawatts in 1980. Based on estimates of the Federal Power Commission on future installed electrical generating capacity of 263,000 megawatts in 1970 and 388,000 megawatts in 1980, the nuclear power generation estimates range from 3.8 to 8.4 percent in 1970 and from 10.8 to 58.6 percent in 1980.

Because the station generating efficiency of a nuclear plant is approximately the same as the generating efficiency of a conventional plant, the water requirements of a nuclear plant will be the same as those for a conventional plant. Therefore from the standpoint of water use, nuclear plants will not require significantly different water demands than equivalent capacity fossil-fueled powerplants. Water quality will not be affected by normal reactor operation because the release of radioactive materials involve low concentrations and small total quantities of such materials. For example the waste effluents from the Shippingport pressurized water reactor are treated by decay, followed by ion exchange, and finally separation of the soluble gases from the liquid. The waste is monitored in the system's test tanks and the proper flow rate determined so that after blending with the turbine condenser cooling water stream the activity on leaving the plant will be no more than 2.6 times 10^{-6} microcuries per gallon.[1] As an illustrative example of such operations, in the first year the quantities of radioactive materials discharged to the Ohio River from the Shippingport reactor were roughly equivalent to those deemed safe (i.e. no adverse effect on stream quality) for discharge on a continuing monthly basis. Accordingly, as far as the future production of nuclear power is concerned, and related to the overall water requirements of the power generating industry, it is concluded that the effect on con-

[1] "The Shippingport Pressurized Water Reactor," Addison-Wesley, 1958, p. 342.

sumptive use of water and water quality will not be of major significance.

Other parts of the nuclear fuel cycle also have process water requirements, but again these do not appear to be significant consumptive uses and need not create water quality problems at the specific locations where these requirements exist. For example, it has been estimated [2] that from the total uranium milling industry some 18 million gallons per day of process water (nonconsumptive use) is utilized. Although there have been some recent indications of a potential stream pollution problem in specific areas due to the chemical toxicity and dissolved radium in process effluents from uranium milling operations, it is believed that such problems are amenable to adequate control by application of available effluent treatment technology, and therefore need not constitute a significant water quality problem. In the production of feed materials (special uranium compounds or uranium metal), requirements are difficult to estimate; however, it has been reported [3] that during 1955 approximately 95 million gallons of treated process water was discharged to the river at the FMPC at Fernald, Ohio (one of three such plants in the United States).

II. Waste Disposal and Water Resources

In the previous discussion, some reference has already been made to the possible effects of effluents from several components of the nuclear fuel cycle on water quality. As indicated, wastes are evolved in all steps of this cycle from the mining and milling of uranium and other ores, to the preparation of feed materials, the operation of nuclear reactors and the chemical reprocessing of irradiated nuclear fuels. In addition, numerous but comparatively minor quantities of wastes are evolved from the use of radioisotopes in medicine, agriculture, and industry. In this respect, the nuclear energy industry is similar to other heavy manufacturing or chemical industries. However, because of the nature of the radioactivity involved and its potential danger as an environmental contaminant, meticulous attention must be given to effluent control. This requirement was recognized at the very outset of the development of the industry and as a result it is probable that, proportionately, more scientific and technical effort and facilities have been focused on the treatment and control of these waste materials than on any other industrial contaminant we have known. At the present time, it is estimated that some $200 million is invested in capital facilities used for waste management. The annual operating cost for these facilities is estimated at $6 million. All of this points to a basic operating philosophy of the nuclear industry—namely, that its operations must be carried out in a manner that does not result in any significant adverse effect on our natural resources.

Generally speaking, the larger volumes of liquid wastes evolved in the industry contain small concentrations of radioactive materials and are amenable to safe, direct discharge or to discharge following treatment by available methods. Such nonconsumptive use is simply the return of process water to the source of supply. Continuous monitoring of the receiving environment is essential to assure that basic radiation protection standards are being met.

Smaller volumes of highly radioactive wastes are associated almost entirely with the chemical reprocessing of irradiated nuclear fuels. These wastes are not dispersed in the environment. They are stored in specially designed underground tanks at the three major chemical processing plants which are all Government owned (Hanford, Washington; Savannah River plant, South Carolina; Idaho chemical processing plant, Idaho; and to a smaller extent the Oak Ridge National Laboratory in Tennessee).

The quantities of wastes to be expected in the future from the nuclear energy industry will depend largely on the extent of growth of nuclear power. Based on nuclear power growth estimates of the order cited in section I of this report and on the present state of technology, it appears that in the next 20 to 30 years the national high-level waste storage demand from a civilian nuclear power program will amount to approximately 50 to 70 million gallons. The quantity of water involved in such storage is a relatively insignificant consumptive use. Effects of catastrophic nuclear accidents on the water resources of a watershed are not considered specifically. Although the

[2] Hearings before the Special Subcommittee on Radiation of the JCAE, 84th Cong., 1st sess. on "Industrial Radioactive Waste Disposal," vol. 1, p. 37.

[3] Joseph, A. B., "Radioactive Waste Disposal Practices in the Atomic Energy Industry," Contract AT(30-1)-1377 with USAEC, Johns Hopkins University, December 1955, NYO-7830.

probability of such an accident is extremely small, there is insufficient data to permit any quantitative assessment of the consequences of such accident as far as water resources are concerned.

From a general water resources standpoint, it can be concluded that the waste management problem of greatest potential significance is that of the dispersal of low-level liquid wastes to our surface waterways or into the ground. As previously stated, it is essential that such operations be carried out in a manner that assures adequate protection of our resources. Experience to date has demonstrated that systems for accomplishing this are known. As a nuclear industry develops, such systems will have to be expanded and it is likely that increased emphasis will have to be placed on in-plant performance criteria rather than special measures in water resource development or control.

III. Nuclear Energy Production and Hydroelectric Development

Nuclear powerplants will be constructed in areas where their electric power production costs can be justified as being lower than proposed fossil fuel or hydroelectric power production costs. At present, the power costs from nuclear powerplants are high, so that there are few areas in the country where a nuclear plant can be justified. As the power costs from nuclear plants are reduced, they will be in a more favorable economic position in some areas where a new hydroelectric or additional hydroelectric plants are to be built. Of course, the nuclear plant will also have to compete with a new fossil fuel plant which could be constructed in the area

IV. Overall Nuclear Industry Water Requirements to 1980

The water requirements in some phases of the nuclear energy industry have been noted previously, and it has been further noted that these requirements do not involve significant consumptive use.

As indicated in section I of this communication, the estimates for nuclear electrical capacity for 1980 vary over a considerable range. The water requirements per megawatt will vary of course with the reactor design and equipment employed. A typical requirement is that of the 60 electrical megawatt Shippingport plant in which the condenser rating[4] is 817 million B.t.u. per hour. Using this plant as a basis, the water requirements for civilian power reactor operations in 1980 will range from 80 to 450 million gallons per minute.

Miscellaneous uses of water include requirements for various laboratory reactors, isotope uses, etc. It is considered reasonable that these miscellaneous uses will not exceed 10 percent of the total estimated as required for civilian power reactor operation

In summary, the overall nuclear industry water requirements for 1980 is estimated to be in the range of 90 to 490 million gallons per minute.

V. Nuclear Techniques in Water Resource Development

Because of the AEC's interest and concern in the fate of radioactive materials which may be introduced into the ground or surface waterways, it is engaged in various laboratory and field investigations of physical and chemical phenomena related to the movement and behavior of fluids in both the lithosphere and hydrosphere. These same phenomena are of direct interest to the hydrologist, ground-water geologist, and other water resources specialists. In initiating and carrying out these studies, the AEC has had the benefit of a close and continuing working relationship with the U.S. Geological Survey over the past 10 years. In general, the main objective of the studies is the quantitative determination and evaluation of the fate of liquid radioactive wastes discharged to the environment and concomitantly the quantitative evaluation of the capacity of specific environments to receive safely certain quantities of radioactive materials. To a considerable extent, this has involved studies of "micro" hydrology and geology to a degree not required prior to the advent of nuclear energy operations.

Perhaps the major nuclear energy technique evolving from such studies is the use of certain radioactive materials to "tag" or label a liquid mass and examine its subsequent spatial and temporal behavior through detection and measurement of the tag. Although chemical tracers have been used for many years prior to the nuclear energy industry for such studies, their application

[4] "The Shippingport Pressurized Water Reactor," Addison-Wesley, 1958, p. 585.

was rather limited due to chemical interaction with media with which the water came in contact. The use of specific radioactive materials (radioisotopes), such as tritium, and the availability of sensitive detection and measuring instruments broadens the possible application of such tracer studies.

In the general field of ground-water hydrology, tracer studies may be of specific value in two fundamental problem areas: (1) problems of recharge, i.e., the movement of precipitation or streamflow into a ground-water aquifer, and (2) problems of water movement within an aquifer. An additional, but partial listing of problems whose investigation represents possible application of nuclear energy techniques is given below:

1. Investigation of consumptive use of water by phreatophytic vegetation in Western United States.
2. Determination of velocity of movement of water through an aquifer.
3. Evaluation of dispersion or diffusion of a "foreign" fluid (e.g., salt-water intrusion) in an aquifer.
4. Determination of soil moisture (by moderation of neutron beams, etc.)
5. Determination of streamflow in areas not accessible for standard instrumentation (use of activity dilution techniques in mountain streams).
6. Continuous and remote determination of snow cover by attenuation of gamma rays.
7. Investigation of eddy diffusion and energy loss in open channels.
8. Investigation of suspended and bed load movement in streams, i.e., river geomorphology studies.

There are undoubtedly other areas related to water resources, conservation, and development in which the application of nuclear techniques will prove useful. In some of the areas listed above, substantial application, at least in a development sense, has already been made. General application on a more or less routine basis has yet to come but the potential value of such application merits vigorous investigative and development efforts in this general area.

It is important to point out that in essentially all such applications, the nuclear techniques represent a tool to facilitate the work of the water resources specialist. They do not represent a substitute for accurate and adequate geologic mapping and other classical geologic, hydrologic, and hydraulic investigation and competence. In themselves, they cannot find or develop new water resources, but may materially assist in the efficient utilization and conservation of our water resources. It is not possible to assess the degree to which the use of such techniques may affect the costs of water resource development because of the early stage of development and application of these techniques.

An additional discussion of this subject prepared previously by the Water Resources Division of the U.S. Geological Survey at the request of the AEC is attached as appendix A.

VI. Nuclear Energy and Desalinization of Brackish or Ocean Waters

The AEC and the Fluor Corp. have investigated the possibility of dual-purpose nuclear reactors for the production of electric energy as well as for desalinization of water. The consequences which result from the coupling of a powerplant to a waterplant tend to make such a combination less economical than a cursory examination would suggest. Difficulties arise because the economical generation of either product (fresh water or electricity) depends upon the simultaneous generation of the other, and the ratio of the total water consumption to the total electrical energy consumption very rarely coincides with the optimum production ratio.

This production difficulty would not exist if the electrical energy could be stored in the sense that water can be stored, but since it cannot, and the simultaneous production of water and electricity is essential to the economics of the inegrated plant, it follows that the load factor of both the water and electrical plant will be dictated by the demand for the nonstorable product, electrical energy. In the calculation of water costs, it is customary to use a load factor of about 90 percent, whereas the average load factor for a modern electric production plant is only about 60 percent. This mismatch in load factor results in a 50-percent increase in all costs except fuel for the waterplant. Of course, it is possible in certain locations to integrate the electric powerplant with an electrical distribution system large enough so that the minimum demand on the system exceeds the output of the powerplant. In this case, a load factor

of near 90 percent could be obtained. The effect of this, however, is to reduce the overall system value of the electricity or increase the cost of the exhaust steam.

The AEC has also investigated the use of a nuclear reactor specifically designed for the production of low temperature and pressure steam which can be used for the evaporation of sea water. It is concluded that while this application is interesting and shows promise in the long-range future, the success of such an application depends largely upon developing an economical evaporator. The development of such an evaporator is clearly within the functions and responsibilities of the Office of Saline Water of the Department of the Interior. At this time, the Office of Saline Water is necessarily vague in their estimates of the potential use or need for such a reactor. This vagueness is due to the uncertainty in their predicted future costs and in the expected results of their current demonstration program.

The Office of Saline Water's demonstration program provides for the construction and operation of five 1-million-gallon-per-day water plants to determine the engineering feasibility and economics of large-scale water production. The AEC is cooperating with them on one of these plants by the construction of its experimental low-temperature process heat reactor authorized for fiscal year 1960 at the site of the Office of Saline Water's west coast sea water distillation plant at Point Loma, San Diego, Calif. In order to determine the cost of producing water from a large-scale nuclear powered sea water distillation plant, the Office of Saline Water contracted with the Fluor Corp. to perform a technical and economical evaluation of such a plant. The AEC cooperated with Fluor in preparing the final report entitled "Preliminary Design Study of an Optimum Nuclear Reactor-Saline Water Evaporator Process" dated August 1959. The results presented in the report are:

> The cost of potable water produced from sea water in a 50-million-gallon-per-day 52-stage flash evaporator, when steam is supplied by a 370 thermal megawatt pressurized water reactor is estimated to be 42 cents per thousand gallons. This water cost includes all costs associated with the operation of the plant. The cost of steam from the nuclear reactor is estimated to be 37 cents per million B.t.u. in the form of steam when all nuclear fuel costs, as well as capital and operating costs, are included.

The AEC staff has estimated the cost of potable water from the largest reactor which could be constructed today for water production. The reactor would be moderated by graphite and cooled by light water and would produce approximately 3,000 thermal megawatts. The technology for this reactor type is well established and the reactor could be built with little or no research and development. The estimated cost of steam from this reactor is 28 cents per million B.t.u. Assuming than an evaporator operating cost of 19 cents per 1,000 gallons can be attained, the water production cost will be 36 cents per 1,000 gallons.

During discussions between the staffs of the Select Committee on Water Resources of the U.S. Senate and the AEC, an earlier preliminary analysis by Mr. R. Phillip Hammond, of the University of California, was mentioned. This paper was printed in the January 1956 "Report of the Panel on the Impact of the Peaceful Uses of Atomic Energy to the Joint Committee on Atomic Energy." In this analysis, it was estimated that it might be possible to construct a nuclear-powered desalinization plant which would produce 1 billion gallons of fresh water per day for 10 to 15 cents per 1,000 gallons. The reactor type employed in this analysis was a boiling heavy water slurry reactor. In order to produce 1 billion gallons of water per day (which is twice the present requirement of the city of Los Angeles), the reactor would have to be capable of a heat output of 10,400 megawatts. A boiling heavy water slurry reactor (of any size) is not within the limits of present technology. At present, the only operating reactor approaching this type is the homogeneous reactor experiment-2 at Oak Ridge National Laboratory. This reactor experiment uses a uranyl sulfate solution in pressurized nonboiling heavy water. The Westinghouse Electric Corp. performed some studies on the use of a slurry in a nonboiling heavy water reactor, but they have discontinued their work. Some work is presently being done at Oak Ridge National Laboratory on slurries in nonboiling heavy water systems. Therefore, the present technical data on slurries in heavy water are quite limited; the data on slurries in boiling heavy water are even more meager.

The AEC Fluid Fuel Reactors Task Force in their February 1959 report to the Division of

Reactor Development stated that to demonstrate the feasibility of a pressurized nonboiling heavy water slurry reactor as a commercial power plant would require in excess of 10 years and $100 million. A program to demonstrate the feasibility of boiling heavy water slurry reactors would undoubtedly require even more time and money.

Because the technical data on boiling heavy water slurries are so meager, it is not meaningful to assign power production costs to such a reactor. The 10 to 15 cents per thousand gallons figure which Mr. Hammond presented seems particularly unfounded compared to the 3,000-megawatt AEC water production plant figure of 36 cents per thousand gallons. The Fluor conceptual evaporator plant above requires 19 cents per thousand gallons for its operation.

The construction and operation of the experimental low-temperature process heat reactor (ELPHR) previously mentioned will provide an experimental facility specifically designed for the production of process heat. Additional basic supporting research on this reactor application will be necessary and will undoubtedly be done at one of the AEC's national laboratories. The amount of research is expected to be quite small because of the wealth of information already available from the Commission's power reactor program. In addition to the ELPHR, the AEC feels that the successful construction and operation of a practical demonstration reactor will encourage the process industry to construct many such reactors using their own resources. If these programs can be pursued as contemplated, it is anticipated that low-temperature process steam produced from a nuclear reactor will be feasible within the next 10 years and that persons contemplating the production of potable water from sea water will be able to buy nuclear heat sources as a standard item of equipment. As previously indicated, however, the economic production of low-temperature steam is only one factor involved in the possible production of competitively priced potable water from brackish or ocean water.

VII. Recommendations for Federal Agency Activities and Suggested Legislation for Application of Nuclear Energy to Water Resources Development

Based on AEC experience to date in working with other Federal agencies (U.S. Geological Survey, Office of Saline Water, U.S. Public Health Service) in areas pertaining to water resource development and conservation, it has been demonstrated that cooperative efforts between two or more agencies can be mutually advantageous. By focusing the specialized competency of each agency on a particular problem area, a more comprehensive attack on the problem is possible. In addition, more efficient use is made of available scientists, technologists, and facilities and cross-fertilization of ideas is enhanced. This does not imply that programs and projects of specific, direct interest to individual agencies should not be vigorously prosecuted unilaterally in accordance with the functions and responsibility of that agency. For example, in connection with the AEC cooperative activities with the U.S. Geological Survey related to the environmental aspects of effluent control, the need becomes apparent for a description and evaluation of the physiographic provinces or subdivisions of the United States in terms of their potential, or lack thereof, for waste disposal. As the industry develops and the need for this type of information becomes greater and more general, it would seem reasonable to suggest that the Survey develop this kind of information as part of their regular program and not necessarily as an AEC-supported project. Accordingly, in this specific case it would seem reasonable to recommend that the U.S. Geological Survey undertake (and receive necessary budgetary support for) this type of project as part of their regular program. This example leads to a more generalized recommendation as follows:

Existing cooperative programs between Federal agencies in areas related to water resources development and conservation should be continued and encouraged. If in

the course of the prosecution of such programs the need for investigative projects of primary interest to one of the agencies is evolved, that agency should undertake such a project as part of its regular program.

In connection with the application of nuclear techniques in water resources development, the desirability of an interagency working group composed of working representatives from U.S. Geological Survey, U.S. Public Health Service, U.S. Forest Service, U.S. Soil Conservation Service, and perhaps others, is suggested in order to accelerate the development and application of such techniques to a wide variety of water resource problems. This would include the training of water resource specialists in these techniques.

In the area of application of nuclear energy to desalinization of brackish or ocean water, it is believed that the present Federal agencies' participation in this effort is established and operating on an adequate basis with the AEC pursuing economical, practical process heat reactors as possible energy sources and the Department of the Interior investigating unit operations directly tied in with the separation and removal of dissolved salts.

At the present time, it is believed that the enabling and authorizing legislation in effect is adequate to permit the AEC to pursue the projects and programs desirable to promote the application of nuclear energy to water resources development. Accordingly, no recommendation in this regard is made at this time.

APPENDIX A

THE USE OF NUCLEAR TECHNIQUES IN HYDROLOGIC RESEARCH AND FIELD INVESTIGATIONS OF THE U.S. GEOLOGICAL SURVEY, APRIL 1959

I. Introduction

This summary statement was prepared in the U.S. Geological Survey, Water Resources Division, for the U.S. Atomic Energy Commission following a meeting of Survey personnel with Mr. Aebersold and others of the Atomic Energy Commission on February 20, 1959. The purpose is to outline problems of geohydrology in which isotopes are or may be used. In addition, certain problems are presented for which solutions are sought, in the hope that specialists may suggest applicable nuclear techniques and assist in the development of instruments of value in geohydrologic laboratory and field studies.

The official interest of the Geological Survey in water begins when, as precipitation, the water falls upon the land surface, and ends when, as rivers and springs, it discharges into the sea. All that happens in between—paths and rates of flow, characteristics of surface and subsurface reservoirs, seasonal and secular changes in storage, the nature and magnitude of chemical and physical interaction with earth materials, evaporation and transpiration back into the atmosphere, availability and utilization, dynamics of sea-water contamination of coastal aquifers, etc.—fall within the scope of water-resource investigations. Much of the work, such as stream discharge and water-level measurements, and quality-of-water analyses, is of a routine nature to provide basic engineering data for current needs. However, efficient use and optimum development demand scientific exploration along many fronts.

For convenience, this discussion is divided into three categories: ground water, surface water, and instrumentation research and development. Many of the most complex problems, however, cut across arbitrary classifications. The following paragraphs outline these problems before presenting more detailed discussion.

1. Division of precipitation into surface runoff, evapotranspiration, and ground-water recharge. Measurement of these variables at any given place, day to day and season to season, is laborious and indirect. Can simple, direct methods be developed?

2. Spatial and temporal chemistry of potable waters. In flowing through aquifers and in stream channels, the chemistry of water changes with location and time because of interaction with earth materials. What factors control this interaction and how may they be studied in the field?

3. Hydrologic inventory and retention times. The total quantity of water, both surface and subsurface, moving through a drainage basin, and the time required to do so must be known to make full and efficient exploitation possible. Geologic and hydrologic mapping and measurement form the bases for these calculations, but there is need for improvement and refinement of present methods.

4. Variability of water resources in time. Knowledge of past secular or cyclic changes in yield of drainage basins may provide a key for predicting future changes. Relative width of tree rings and relative thickness of clay varves have been used to infer changes in past conditions. Both these methods are uncertain. Is there any record of past hydrologic conditions amenable to positive interpretation?

5. Geomorphology of river valleys. The manner by which river valleys develop through geologic time, in relation to terrain, climate, sediment load, etc., is far from being a purely academic study. A thorough understanding of these processes would in turn provide better understanding of the effects of reservoir development, land use, flood control, etc. The problem has many facets and requires the development and utilization of many different techniques. Is there a nuclear technique, for example, that would give the age of a deposit of river alluvium?

II. Ground-Water Hydrology

Tracers may be used in ground-water studies, when conditions are favorable, to determine *where* a labeled mass of water travels, *how* it travels, and *how fast* it, or the most rapidly traveling part of it, travels. In the general field of ground-water hydrology, tracer studies are of actual or potential value in two basic problem categories: (1) problems of recharge, which relate to movement of precipitation or streamflow into an aquifer, and (2) problems of water-movement paths within an aquifer.

Tracers have been used to determine permeability by ground-water velocity methods using uranin dyes, or electrolytes, such as sodium or ammonium chloride. The development of the Thiem (1906) and particularly the Theis (1935) pumping-test methods provided a more dependable and valid method of determining permeability, and the velocity methods were abandoned. Dye tracers were also used to trace the course of underground "streams" in cavernous limestone, and to label a source of pollution to determine if the dye (and, therefore, pollution) appeared in a water supply.

The use of radioactive tracers in recharge studies

Recharge is the replenishment of ground water by infiltration of precipitation, or by infiltration from surface-water bodies. The water moves downward through the

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zone of aeration by gravity and molecular attraction. Periods of heavy or prolonged precipitation apparently produce "waves" of recharge moving downward through the zone of aeration to the water table. The precise manner in which water moves through this zone is not well understood. Since all ground water used must be either replenished by recharge or taken from storage, the process is a vitally important subject for research. Tracer studies may extend greatly our knowledge of this important process. It would be highly desirable to be able to label a "wave" of precipitation moving down through the zone of aeration and study in detail its movement down to the water table and its relation to other "waves."

When percolating water reaches the water table it may accumulate in layers that correspond to successive periods of recharge. If these layers of annual accretion could be delineated there would be available direct measurement of the volume of recharge and its rate of movement downgradient. A method of delineating the volume of water beneath the water table that has been recharged since 1954 is provided by a sharp increase and continued higher level of tritium in precipitation since that date.

Much potential recharge or replenishment of the ground water is intercepted by the root systems of plants, and is discharged by transpiration. The greatest natural wastage of water is by plants known as phreatophytes (water-loving plants whose roots tap the water table or the capillary fringe above it). Phreatophytes grow on some 16 million acres in the 17 Western States, and discharge 20 to 25 million acre-feet of water annually through transpiration. This large-scale wastage of water in the water-short West is of great concern to hydrologists. Solution of this problem would be aided by a better understanding of how ground water is absorbed by root systems, rates of uptake of water by the different species of plants, and consumptive use of different plants in various hydrologic environments. This problem could be attacked through the use of a suitable radioactive tracer, such as a gamma-ray emitter with a short half life.

THE USE OF RADIOACTIVE TRACERS IN AQUIFER TRANSMISSION RESEARCH

Problems relating to movement of water within an aquifer are amenable to tracer research, with certain limitations. The rate of movement of water in the aquifer must be sufficiently rapid to permit the tracer experiment to be completed within a reasonable period of time. From the standpoint of practical planning, the duration of an average tracer experiment should not be expected to exceed a few years.

Velocity of ground-water movement depends chiefly upon permeability and hydraulic gradient. In most aquifers either the permeability or the hydraulic gradient is too low to permit ground-water velocities of more than a few feet a day. Tracer experiments planned for such velocity environments must, therefore, be long in duration or must sample only a very short distance through an aquifer.

Optimum conditions for tracer experimentation can be found in aquifers of high permeability. These include such rocks as limestone and gypsum, which may contain really extensive solution caverns, basalt which may contain such water-transmitting features as lava tubes, joints and other fractures, and clinkery or blocky lava zones, or alluvial deposits which contain coarse sand or clean gravel. Extremely high velocities are possible in such environments, particularly when a high gradient is available. Bierschenk (1958, pp. 1835–1839) determined by fluorescein dye tests velocities up to 770 feet a day in highly permeable alluvial sand and gravel in which a radioactive-waste-disposal ground-water "mound" provides a steep hydraulic gradient.

There are two important problems involving transmission of water within an aquifer. The first of these is determining *maximum* rates of movement of ground water in highly permeable zones. Some hydrologists are beginning to suspect that these velocities may be far higher than is generally realized. The second problem involves rates of dispersion and diffusion of a "foreign" liquid (such as radioactive liquid effluent) in an aquifer. Both problems are of vital importance in connection with radioactive-waste disposal to ground-water environments.

THE PROGRAM OF RADIOACTIVE TRACER RESEARCH IN THE GROUND WATER BRANCH

The Geological Survey has started a research project in an attempt to delineate the layer of post-1954 recharge beneath the Wharton Tract watershed, near Burlington, N.J. The project area is underlain by a highly permeable deposit of Pleistocene sand. Samples of water have been taken for tritium analysis at eight locations. At each location water has been collected from depths of 5, 25, 50, and 100 feet.

In the High Plains of southeastern New Mexico and northern Texas pumpage for irrigation is large, and recharge is small. Recharge is chiefly through sinks which perforate a caliche layer. Ground-water withdrawal in the area is virtually all from storage. Here the processes of recharge present a critical problem. A tritium tracer project was begun here in the fall of 1958 and will continue to July 1960. The first step of the project involved sampling of water from wells near sinks to determine the amount of movement of recharge water since 1954. This water would be high in bomb tritium. In addition, it is planned to label water in a recharge well and trace the rate of movement of the labeled recharge by sampling nearby observation wells.

A second type of tracer research using bomb tritium is exemplified by two projects undertaken by the Geological Survey during the period of Russian and United States weapon testing of last spring. Project objectives are designed to trace thermonuclear tritium fallout peaks from the precipitation, through the ground-water system and into the stream runoff. During the period February 28 to July 30, semimonthly samples of water for tritium analysis were taken from precipitation, runoff, and ground water in two small drainage basins. One basin, at Lebanon State Forest, N. J., is underlain by highly permeable Pleistocene sand, and the other basin, at Black Earth Creek, near Madison, Wis., is underlain by unconsolidated Pleistocene sand and gravel valley fill, and indurated

Cambrian sandstone. During the period of the sampling there occurred several sharply defined peaks in tritium fallout.

The Geological Survey is now engaged in field tracer research on a problem at Lake McMillan, N. Mex. Lake McMillan is a reservoir on the Pecos River near Carlsbad, N. Mex., underlain by gypsum deposits that are so cavernous that all but floodwaters are drained out underground and reappear in the river at Major Johnson Springs about 4 miles below the reservoir. Tracer research here is devoted to a study of the storage capacity of the aquifer. A reasonably accurate quantitative answer to this problem may be provided by computing the amount of dilution of the labeled water after it leaves the lake and moves through the aquifer. The greater the ratio of underground storage to lake storage, the greater will be the dilution. Travel time through the aquifer also will be studied. During the 1959 fiscal year the tritium "background" of the hydrologic system is being determined. It is planned in the 1960 fiscal year to label the lake waters with manufactured tritium and trace the labeled water through the aquifer.

THE USE OF RADIOACTIVE TRACERS IN LABORATORY RESEARCH

A radioactive tracer experiment is now underway in the Phoenix office of the Ground Water Branch. The problem here is to determine quantitatively the degree of dispersion and diffusion of a miscible "foreign" liquid traveling through a homogeneous porous medium. A block of uniformly sized sand was formed by cementing the grains with epoxy resin. The porous medium is brought into equilibrium with stable phosphorous by prolonged throughput of phosphoric acid. Radioactive phosphorous (phosphorous 32) is then passed through the system from a point source. The dispersion and diffusion of the radioactive phosphorous is then determined by cutting the block in successive cross sections and measuring the dispersion and diffusion by exposing the slices to photographic emulsion plates.

It is also planned to use a radioactive tracer in laboratory research to determine diffusion and dispersion activity along an oscillating salt water-fresh water interface.

III. Surface-Water Hydrology

USE OF RADIOISOTOPES IN OPEN CHANNELS

The Water Resources Division is using radioisotopes as tracers in natural streams. A satisfactory tracer has been long sought to aid in the solution of various problems in fluid mechanics. The properties possessed by some radioisotopes make them very effective in gaining insight to these problems.

Chemical tracers have several rather severe limitations: (1) Many chemical additives that can be detected at low levels alter the specific weight of the fluid; (2) the limits of detection of chemical and dye tracers are greatly restricted in comparison with radioisotopes; and (3) instantaneous observation of tracer concentrations becomes a monumental task with chemical tracers.

From controlled experiments in which radioisotopes are injected into streams, a great deal of knowledge can be gained. At present we cannot predict the dispersal pattern of soluble material in a stream. Such patterns can be observed with isotopes. We believe that these patterns can be related to the channel geometry and the flow characteristics. Glover and Daum (1957) studied the dispersal of dissolved material in streams. They would probably have preferred to use isotopes in favor of salts because of the same limitations brought forth in earlier studies. However, techniques were not available. Also closely associated with the dispersal process are such phenomena as eddy diffusion and energy loss in open channels. The use of radioisotopes in controlled experiments to trace the change in dispersal patterns caused by channel bends will give us considerable insight into the associated energy losses.

The use of radioisotopes in research in the mechanics of open channel flow will continue to expand over the years as better instrumentation becomes available and more techniques are developed.

USE OF ISOTOPES IN SEDIMENT TRANSPORT

A basic assumption made in measuring the concentration of suspended sediment in streams is that the sediment is moving at exactly the same velocity as the water. It would be most useful to be able to check the validity of this assumption. In fluvial mechanics the most difficult observation to make quantitatively is the movement of the heavier particles on and near the bed of the stream (bedload). This now is only possible at a natural or artificial constriction which produces sufficient turbulence to place these particles in temporary suspension so that the suspended sediment sample includes a bedload. A procedure using "labeled" bed material and tracing its movement directly with monitoring equipment would simplify such studies. Thus the bedload movement would be observed in its normal behavior—not the unusual case of the natural constriction or the artificial situation produced by a manmade structure.

Our knowledge of the mechanics of sediment transport is at best imperfect. Radioisotopes would provide us with a tool to study aggradation and degradation and to learn the history of the particles involved in these processes. We could observe how long the particles stay in bars and shoals before they move to new locations. Then these data can be related to the sequence of hydrologic events in streams.

Several studies using radioisotopes as tracers have been conducted in tidal estuaries to observe silt movement. We know of no use to date of isotopes in purely alluvial streams to trace sediment movement or study sediment mechanics. The radioisotope holds great promise for application to this problem and is still to be exploited.

Library research is being undertaken to study the use of isotopes for sediment movement this fiscal year. The radio instrumentation developed to study mixing and mixing and disposition in surface water will be the same type needed in sediment tracing. It has been demonstrated by Krone of the University of California at Berkeley that gamma emitters must be used and scintillation techniques employed. Plans have been made to trace some sediment in the field and/or the laboratory next fiscal year.

Friedman and others (1956) used deuterium in an attempt to determine the movement of water in and out of Lake Maracaibo but results were not conclusive. Lately, studies were made to evaluate the effects of evaporation suppressants over Lake Hefner. Deuterium measurements were made in order to compare the water-deuterium balance.

IV. Instrumentation Research and Development

Among the needs of the geohydrologist engaged in water-resources studies is that of more sensitive and quantitative instruments for radioisotope determinations in the field and the laboratory. Following is a list of suggested instruments and instrument concepts which it is felt warrant attention:

1. Measurement of suspended sediment concentrations by radioactivity. The objective is to develop a continuous recording device for measurement of suspended sediment concentration by either absorption or backscatter of radiation. Preliminary investigations with instruments similar to neutron soil-moisture meter indicate that this approach may be promising for sediment-density measurement.

2. A field-type tritium detector that can easily and quickly measure tritium concentrations in surface streams and ground water that has been labeled with manmade tritium. A research and development project which would seek to further simplify laboratory tritium-analysis operations would also be of very great value to the hydrologist.

3. A multichannel pulse-height analyzer for use with a well probe in logging wells and test holes is needed. It should be able to identify various isotopes under field conditions.

4. Field detection of radioactivity by sensitive emulsions. It is well known that field monitoring of radioactivity by field versions of laboratory instruments is expensive and relatively unreliable. The instruments are not sufficiently rugged for continuous exposure to field conditions. It is suggested that photographic or other sensitive emulsions be employed in controlled experiments. Conceivably a continuously recording emulsion strip could be developed which could be drawn through a well by a timed mechanism. The blackening of the sensitive strip would automatically give a record of radioactivity versus time. Requirements are:

(*a*) Waterproof emulsion, possibly compounded of silicones.

(*b*) Sensitive emulsion—generally more sensitive than the emulsions used in laboratory autoradiography.

(*c*) Minimum absorption—to detect C-14 and T.

5. Continuously recording field meters for strontium 90 and cesium 137. The two most significant artificial isotopes from the health and safety standpoint appear to be Sr^{90} and Cs^{137}. Instruments to continuously monitor these two isotopes in water should be developed. Concentration of the isotopes is required and could be achieved by an automatic cycling ion-exchange absorption and elution device. The isotopes could be differentiated on the basis that Cs^{137} is a gamma emitter while Sr^{90} is a beta emitter. Ion exchange (or other collection method) could be made relatively specific for these two isotopes.

Operation of the instrument would be cyclic or intermittent, rather than continuous (because of the necessity to concentrate isotopes). Therefore, the term "cyclic" analyzer is to be preferred over "continuous" analyzer.

6. "Cyclic" tritium analyzer for field use. Inasmuch as tritium is the preferred isotope for ground-water movement field studies, a field tritium recorder is needed. Because of the necessity to observe MPC levels in isotope injection the sensitivity would be in the $\mu\mu c$ range. Cyclic operation is thus required with a measurement cycle following a concentration cycle. Fast, high-current electrolysis or automatic fractional distillation are conceivable approaches. Measurement could be by automatic liquid scintillation or gas-phase counting. Instrumentation problems would be extremely difficult.

Because ground water moves slowly, the cycle of operation for the analyzer could be slow without much danger of missing a labeled peak. Thus the concentration cycle could operate relatively slowly.

7. Mobile field laboratory for radioactivity. Many water-movement studies are facilitated by immediate analysis of the isotopic concentration. The ideal solution to the problem is a continuous recording radioactivity meter or portable meter carried by an observer. The instrumentation difficulties are large and perhaps prohibitive. A compromise between the ideal situation and the present situation, which requires sending the sample into a laboratory, would be a mobile field laboratory set up in a panel truck. The truck could be moved to the site of the investigation and could be equipped for the most part with selected commercial instruments. The sensitivities of some special commercial instruments should be adequate for some relatively high-level tracer experiments.

A field spectrographic laboratory set up in a truck has been used by the Geological Survey. That experience could be utilized for problems of shock mounting, power supply, etc.

8. Field instrument for following tracer movement by neutron absorption—the use of boron. MPC tolerance levels could be disregarded if a nonradioactive tracer capable of detection with typical radioactive-isotope sensitivity could be used. Conceivably such a tracer could be a strong neutron absorber (high cross section for capture). The effect of the tracer would be to attenuate a neutron flux and the reduction in intensity would be measured. Only boron presents a capture cross section within range of consideration. Borates introduced into natural water would probably be subject to the usual absorption and exchange reactions associated with chemical tracers, and hence would be valueless. However, the possibility exists of synthesizing a boron compound not subject to these reactions. It is suggested that the chemistry of boron be explored and that promising compounds of boron be tested in the laboratory for their reactions in typical synthetic ground-water environments.

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